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DREV AND THE EO PROPAGATION ASSESSMENT IN COASTAL ENVIRONMENTS (EOPACE) TRIAL

by

J.L. Forand and D. Dion

October/octobre 1998

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Approved by/approuvé par

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Section Head/Chef de section

18 Sept. 98

Date

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ABSTRACT

This memorandum describes the basic objectives of the EO Propagation Assessment in Coastal Environments (EOPACE) trial and gives an account of DREV's participation in EOPACE. Particular emphasis is placed on the two trials held during the spring of 1996 and the trial held in August of 1997.

After the Introduction, the memorandum provides some background information on EOPACE and its objectives. The following section sets out the experimental time-line, describes the experimental sites, and lists most of the participants, and their contributions to EOPACE. The last section gives a more detailed description of DREV's participation and particular interests.

RÉSUMÉ

Ce mémorandum décrit les objectifs fondamentaux des essais "EO Propagation Assessment in Coastal Environments (EOPACE)" et fournit un résumé de la participation du CRDV à EOPACE, en particulier aux deux essais du printemps 1996 et à celui d'août 1997.

Après l'introduction, dans la deuxième partie du mémorandum, on fournit de l'information de base et on énumère les objectifs d'EOPACE. Dans la troisième partie, on décrit l'horaire expérimental, puis les sites expérimentaux et on fournit une liste des participants et leurs contributions, puis on donne un aperçu de leur apport à EOPACE. Dans la dernière partie, on fournit une description plus détaillée de la participation et des intérêts particuliers du CRDV.

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EXECUTIVE SUMMARY

Due to the increasing importance of EO sensors and probes used by today's military, and the growing importance of the coastal environment, the propagation of electromagnetic radiation in this environment is a question of extreme importance and relevance. Unlike, the open ocean, the optical properties of the marine boundary layer (MBL) in the coastal zone is heavily influenced by both the neighbouring landmasses and the surf zone.

Due to DREV's interest in Infrared Search and Track (IRST) systems, it has become increasingly involved in studying the optical effects of the MBL on imaging systems during the last few years. In 1993, we participated in the Marine Aerosol Properties and Thermal Imager Performance (MAPTIP) trial off the coast of The Netherlands in the North Sea. As a result of our work on the refractive effects of the MBL on optical systems, we were asked by the US to participate in their EO Propagation Assessment in Coastal Environments (EOPACE) trial. This trial began early in 1996 and is expected to continue into 1999.

After the introduction, the memorandum provides some background information on EOPACE and its objectives. The following section sets out the experimental time-line, describes the experimental sites, and lists most of the participants, their contributions and some of their future plans. The last section gives a more detailed description of DREV's participation and of our particular interests.

1.0 INTRODUCTION

Due to the increasing importance of EO sensors and probes used by today's military, and the growing importance of the coastal environment, the propagation of electromagnetic radiation in this environment is a question of extreme importance and relevance. Unlike, the open ocean, the optical properties of the marine boundary layer (MBL) in the coastal zone is heavily influenced by both the neighbouring landmasses and the surf zone. To better understand these effects on EO systems, a number of different trials have been undertaken over the last number of years.

The Marine Aerosol Properties and Thermal Imager Performance (MAPTIP) trial took place during October 1993, over the North Sea off the coast of The Netherlands. It was a NATO AC/243 (Panel 04/RSG.8 & RSG.5) unclassified field trial for determining the atmospheric propagation effects on electro-optical systems whose principal objectives were (Ref. 1):

1) to improve and validate vertical marine aerosol models by providing an extensive set of aerosol and meteorological measurements within a coastal environment, at different elevations and for a range of meteorological conditions.

2) to perform aerosol and meteorological observations within 10 m of the ocean surface with a view to extending existing aerosol models to incorporate near-surface effects.

3) to assess marine boundary layer effects on thermal imaging systems.

This trial included the participants from many NATO countries and was highly successful. Following MAPTIP, two further international trials were proposed for 1996. The US proposed the EOPACE trial (Ref. 2) and invited participation from other NATO countries, while NATO (Panel 04/RSG.5) proposed the Low Altitude Point Target Experiment (LAPTEX) trial (Ref. 3). DREV is a participant in both trials as their objectives are seen to be both complementary and supplementary to our existing knowledge base.

The next section describes the primary objectives of the EOPACE trial, followed by details of the trial's time-line, and the planned experiments. The subsequent section focuses on DREV's participation in the trial, while the final section presents the current status of the EOPACE trial.

This work was carried out between October 1995 and April 1998 under work unit 1AB11, Propagation Effects in the Marine Boundary Layer.

2.0 EOPACE

The increasing use of infrared (IR) systems by Armed Forces around the world for the surveillance, detection, and identification of possible threats is becoming very important in the coastal environment. As a result, the US has sponsored EOPACE to improve the performance assessment for EO weapon and sensor systems operating in a coastal environment, and given it the following primary objectives:

1) to quantify effects of coastal aerosols on EO propagation extinction,
2) to develop mesoscale models and data assimilation systems,
and 3) to evaluate EO systems performance.

The distinguishing feature of EOPACE is its intent to conduct continuous long-term (several months) experimental measurements with the addition of occasional periods of more intensive investigation. As the Space and Naval Warfare (SPAWAR) Systems Center in San Diego (previously NRaD) is organizing the trial, the long-term observations are being performed using primarily their resources and personnel in the San Diego area. The observations are being carried out to assure that the largest possible range of atmospheric conditions, in the San Diego area, will eventually be studied. During the intensive measurement periods (1-3 weeks), other groups have been adding their equipment so that more extensive data pertaining to the primary objectives could be obtained. The following sections discuss the particular areas of study related to the three primary objectives.

2.1 Coastal Aerosols

The performance of IR systems depends upon the optical properties of the intervening atmosphere. Consequently, the optical properties of the aerosol present in the coastal environment, their size, concentration, chemical composition, and distribution all have an effect on the performance of IR systems. As most previous efforts have gone into understanding an open ocean aerosol, a number of aspects of the coastal aerosol are not well understood. In this respect, it is hoped that EOPACE will push the development of an effective coastal aerosol model based on measurable parameters, the development of remote sensing techniques for the determination of the optical properties of coastal aerosols, and a better understanding of the role played by the aerosols produced within the surf-zone.

2.1.1 Aerosol Distribution and Composition

Aerosols in the coastal region are a mixture of primary particles from both man-made (anthropogenic) sources, natural sources (maritime and continental), and secondary particles produced from the primary particles through various chemical conversion processes. Over water, the most important chemical property, with respect to its effect on visible and IR radiation, is the hygroscopicity of the aerosols (i.e. the ability for smaller particulate aerosols to grow by the adsorption of water molecules). This is because the aerosol size distribution is the most important factor in determining its refractive index, scattering coefficient, and absorption coefficient at any particular wavelength. The greater temporal and spatial variability in weather patterns within the coastal environment also cause the final composition of the aerosol to be very complex and highly variable. Thus, a much more complete knowledge of its composition and concentration at different locations and under varying types of weather conditions is equally important in the determination of its optical properties over the entire coastal region. Several methods are available for determining its chemical composition. These include HI volume impactors, various chemical analysis devices, and high temperature stability spectra of the accumulation mode aerosol. As

measurements of the aerosol composition and concentration can not be continuously performed at an infinite number of sites, other approaches are required to predict the optical properties of the aerosols. Three approaches, which can be combined, are currently used to attack this problem: 1) physics based meteorological and aerosol models can be developed to predict the time-evolution of the pertinent parameters; 2) the use of an air mass parameter (AMP) with characteristics based upon the origin and trajectory of the air mass; and 3) remote sensing using satellites, aircraft and surface-based systems to provide instantaneous aerosol distributions.

Multi-wavelength images from satellites or high-flying aircraft can provide large-scale views of many physical phenomena occurring within the coastal zone. In southern California, several satellites obtain such images on a routine basis and can provide measures of the distribution, concentration and optical properties of the coastal aerosols. The results obtained by these satellites (or aircraft) and the algorithms used to process the data, can then be ground-truthed using air samples collected by low-flying aircraft following predefined trajectories, and by ground-based lidar systems at various sites. These data can also be correlated with the other, previously mentioned physical measurements of the aerosol composition and concentration. The lidar and low-flying aircraft can also provide information on the horizontal and vertical variability of the aerosols. Standard meteorological stations capable of measuring the humidity, pressure, air and sea temperature, wind velocity, and wave height are also required and should be present at each lidar site. Vertical profiles of these standard meteorological parameters can also be measured using balloon sondes and aircraft. Radon (isotope 222) detectors, condensed nuclei (CN) counters, visibility meters, sun photometers, and other specialized equipment can also be used at these sites in order to provide further correlation with the air mass parameter.

2.1.2 Surf-Generated Aerosols

The surf-zone is one of the principal sources of a sea-salt aerosol in the near coastal

environment. Waves breaking along a coastline generate copious amounts of fine saltwater droplets (a sea-salt aerosol) which can be propelled, as plumes, many meters into the air. Local winds then redistribute the smaller particles throughout the coastal environment. With its long fetch, southern California is a good place to study this source of a sea-salt aerosol, as remote storms in the South Pacific often produce significant swell, even when the local winds are relatively calm. This situation allows the possibility to separate the effect of local winds from that of the breaking surf on the generation of sea-salt aerosol. Long-term measurements of the electric field created by the charged droplets can provide relative aerosol concentrations that can be calibrated during the intensive periods using aerosol spectrometers to measure the aerosol size distribution. Simultaneously, Lidar system can be used to map the dynamic distribution of the aerosol and its plumes.

2.1.3 EO Transmission

Navies around the world need more accurate predictions of EO transmission at diverse geographic locations. While measurements can be made in some cases, physical models, such as LOWTRAN and MODTRAN (Ref. 4), can be used under any circumstance. Generally, these models use a number of standard local meteorological inputs (temperature, wind velocity, air pressure and relative humidity) to calculate the transmission using well-established optical properties for the most common components of the atmosphere. However, the propagation of IR radiation at low elevations is also affected significantly by dynamic changes in the horizontal and vertical aerosol concentration and the relative humidity, which are not usually measured near the surface. For the open ocean, existing propagation codes, such as MODTRAN, which use aerosol models like the Navy Maritime Aerosol Model (NAM) and the Navy Oceanic Vertical Aerosol Model (NOVAM) (Ref. 5) do a reasonable job in calculating the transmission. However, in the coastal environment, particularly at low elevations, where the atmosphere is much more temporally and spatially dynamic, this is much less the case. Thus, one of the goals of EOPACE has been to make transmission measurements at visible, mid-infrared and far-infrared wavelengths over

various near-horizontal paths that include the effects of both the surf-zone and the near-coastal environment. These measurements can then be compared with various model predictions which use the measured meteorology and aerosol size distribution as inputs. One effect which is not often taken into account and which must not be ignored is that of refraction. The importance of the refractive properties of the marine boundary layer have not always been as well recognized, but the resultant focussing or defocussing of EO radiation can have very important effects on the measured transmission. This effect is discussed in more detail in section 2.3.

2.1.4 Air Mass Parameter

The current aerosol models used by the US Navy are NAM & NOVAM. Both models require the use of an air mass parameter (AMP), which describes the quantity of background (non sea-salt/continental) aerosols to the total aerosol. In other words, it is a measure of how much continental aerosols are present in an air mass. Presently, the AMP is assigned a number between 1 (relatively pure maritime aerosol) and 10 (significant continental component) that is based upon estimates of the time elapsed since the air mass left the continent and moved over the ocean. In general a measure of the AMP can be obtained using one of the following four methods: 1) from a trajectory analysis of the air mass, 2) from radon (222) measurements, 3) from visibility or nephelometer measurements, and 4) from measured concentrations of condensation nuclei (CN). In the open ocean (AMP = 1,2), where there is little temporal or spacial variation, this works quite well. However, as the background component becomes more important and dynamically variable near the coastal area, the AMP must reflect these temporal and spatial variations or its performance will suffer. The difficulty, is that it is not clear how these four methods can be modified to provide the required dynamics. During EOPACE, the quantity of the background aerosol component will be measured, over the long-term, at many strategic locations throughout an extended geographical area. The combination of these measurements with other long-term meteorological measurements given by ground stations,

radiosondes, and satellites, and improved mesoscale modelling will hopefully give us a better understanding of the variables that affect the air mass parameter.

2.2 Mesoscale Models and Data Assimilation

The coastal environment is characterized by irregular gradients near the sea surface that can create complex mesoscale structures that are not always adequately represented by conventional meteorological data. To overcome these limitations, coastal mesoscale weather prediction models need to incorporate detailed physical models of both energy and momentum transfer. However, as data for these models is generally only sparsely available over most mesoscale domains, a great burden is placed upon the physics within the models and on the data assimilation schemes. The goal of data assimilation is to create an initial 3D grid of various weather parameters at a much finer spatial scale than that over which the actual data was measured. Then, this array of data is run through the mesoscale models so as to predict future weather patterns. Due to the existence of small-scale fluctuations in the coastal environment, and current limitations on the physics within the models, this process can sometimes produce disastrous results. Furthermore, most of these models lack the ability to calculate parameters that are critical to the performance of optical systems.

To improve our current ability to predict the performance of EO systems in any littoral region of the world, the physical models incorporated into the current mesoscale models must become more complete. Current deficiencies include an incomplete understanding of the important physical processes affecting the composition, concentration and distribution of aerosols, the lack of a physically representative 3D aerosol distribution model, an inadequate understanding of the trajectories followed by air parcels within the marine boundary layer (MBL), and the lack of 4D (spatial and temporal) data for model validation. This is a large task, but it is hoped that a suitable 4D database can be built from the many physical measurements to be obtained by other groups (see descriptions in the other sections), over both the short and long term, and then to use it to develop improved physical

models. A second factor, which has not really been discussed, is the effect of the coast's geography on the trajectories of air parcels in the MBL. This is quite significant when one considers the notable meteorological variations that can be found between a headland and a cove, or below a cliff or over a beach. Consequently, the development of realistic models of a coastal region's geography and its effect on the movement of air parcels is a field that requires study.

2.3 EO Systems Performance

Naval operations are being carried out both in the open ocean and in coastal regions. To protect themselves from dangerous low-flying missiles that are often difficult to detect using radar, many navies are developing infrared search and track (IRST) systems to continuously scan the horizon for such threats. Passive and active (laser) imaging systems and laser range-finders are being installed on ships, submarines and surveillance aircraft to detect, and identify IR targets. The ability to detect such threats depends upon the contrast between the radiation received from the target, and that received from the surrounding background. However, the constituents of the intervening atmosphere which absorb *and* scatter the radiation from the target, the vertical gradients which refract the radiation from the target, and polarization effects all help define the operating limits of these systems. The growing use of optical systems is also increasing the need for tactical decision aids (TDA's), so that a commander can better understand the limitations of their systems, the quality of the information they are being given from these systems, and can make reasonable predictions of their performance under future weather conditions.

2.3.1 Backgrounds and Clutter Effects

The ability to detect targets in an image depends upon the contrast (or signal/noise ratio) between the target (or signal) and the background (or noise). In the coastal environment, the background can be a composite of sea, sky, land, or even man-made

sources. Clutter is that part of the background whose signal is highly variable and of a spurious origin. It can further mask a target and can cause an increase in the mistaken detection of targets (or false alarms). Its significance depends largely upon the geometry between the sun (or other bright, man-made sources) and the detector, and the reflectivity (or diffusion) of the background scene's various components. Thus, for example, we can have problems of sun-glint (reflection of the sun) off a rough or smooth sea, or even off the glass or metal structures of a city's buildings. Consequently, the operation of optical systems under high clutter conditions is very challenging and requires the development of techniques which suppress their impact on our detectors, and intelligent algorithms that can reduce the induced false alarm rate.

2.3.2 Polarization Effects

The polarization of radiation reflected and emitted by the sea are important effects that are often neglected. In the 8-12 micron band (far-infrared), measurements taken over the sea have shown that its far-infrared emissions can be polarized up to 30% when viewed near the horizon. As a result, it should often be possible to improve the contrast between man-made targets, which normally have little polarization, and a polarized sea background. Visible and 3-5 micron (mid-infrared) radiation, which is reflected off a sea surface near the Brewster angle (~ 35° above the horizon) are both strongly polarized horizontally. In fact, under a flat sea it could approach 100%. Consequently, an improvement in the detectability of a target, under sun-glint conditions (the direct specular reflection of sunlight when the sun is low to the horizon), should be possible through the suppression of the resultant horizontally polarized sea clutter by only making vertical polarization measurements. To clarify these points and the background conditions (sky, sea and land characteristics) under which they may be beneficial, unpolarized and polarized measurements of calibrated, low elevation targets have been gathered under a variety of meteorological conditions, and backgrounds during EOPACE.

2.3.2 Absorption, Scattering and Refraction Effects

The absorption and scattering caused by the intervening atmosphere between a target and a detector are perhaps the most important phenomena to be studied, as they impose very definite limitations on the operation of any optical system.

The amount of absorption depends upon the radiation's wavelength, and the composition and density of the intervening atmosphere. In the infrared, our preference for the 3-5 micron and 8-12 micron bands is largely due to the low absorption in these bands by the atmosphere. However, the variable and often increasing concentration of water vapour and aerosol particulates near the sea surface affects the absorption within both these bands and can significantly reduce the amount of radiation received by a detector from a target.

The amount of scattering also depends upon the radiation's wavelength, and the composition and density of the intervening atmosphere. In particular, it depends upon the size distribution and the index of refraction of the atmosphere's aerosol components. The effect of scattering is to redirect the radiation coming from a target into other directions, which may or may not be within the field of view of the detector. The effect on an optical system is a reduction in the amount of incident radiation, and a blurring of the target's image.

Refraction is another important, though often neglected, wavelength dependent effect. The stronger density gradients of the atmosphere near the sea surface cause radiation to be deviated from a straight line and to be bent in the direction of greater density. As shown during the MAPTIP trial (Ref. 6), the maximum detection range of a target, assuming no extinction of the radiation, depends largely upon the air-sea temperature gradient. In fact, detection ranges up to five kilometres short of the expected horizon were measured during MAPTIP. Refraction of the radiation coming from a target can also produce secondary images (mirages), and can focus and defocus (like a lens) the radiation. This can result in the observation of secondary images (as was observed during MAPTIP) and a decrease or

increase in the intensity of the radiation received from a target (also observed during MAPTIP).

Extinction (scattering and absorption) of the radiation emitted by a source over a path in the atmosphere can be measured using IR transmissometers. Low-elevation paths over water of 7, 15, and 21 km have been used during EOPACE. To properly characterize the optical paths, basic meteorological measurements (including water temperature) have been obtained from buoys near their mid-paths, and from land stations at their endpoints. Furthermore, a boat has traversed the paths so as to measure the horizontal variability of the meteorological parameters and the aerosol size distribution. To directly monitor the effect of refraction on the transmission measurements, simultaneous high resolution images of a set of light sources placed at the far endpoint of all three paths have been obtained so as to allow experimental validation of various MBL refraction models. These models include LKB (Ref. 7), PIRAM (Ref. 8), and LWWKD (Ref. 9).

2.3.4 Turbulence and Scintillation

While spatial variations in the index of refraction of the intervening atmosphere can create mirages and other relatively static effects, its temporal variation, due to atmospheric turbulence, also has important consequences. Movement of the air, particularly when it is being heated, causes scintillation (time variations in the received intensity) and beam-wander (the quick vertical and horizontal motion of the observed target). For imaging systems, beam-wander increases the blurring, such that objects become less defined and thus, reduces their contrast. Furthermore, as the scintillation of the received radiation occurs at time-scales of less than 1/30 of a second (this is less than the standard frame rate of a camera), significant variations in the contrast (or signal/noise ratio) can be expected from frame to frame (or measurement to measurement). Measurements of the refractive index structure parameter (C^2_n) or the temperature structure parameter (C^2_T) can be obtained using sonic anemometers or other devices. Measurements of C^2_T have been made on the buoy placed at the midpoint

of the 15 km transmission path.

3.0 EXPERIMENTAL DETAILS

This section starts by showing the EOPACE time-line and its status as of Feb. 1998. This is followed by a description of each of the principal experimental sites used to date, and the types of experiments that have been planned or carried out at each site. Finally, a list of the principal groups participating in EOPACE, and the type of measurements they have provided is given.

3.1 The Time-line

The time-line given in Table I was proposed during the fall of 1995 and is being quite strictly adhered to. The time-line gives the time and place of the meetings, and the time and place for the various intensive operation periods (IOP's). The four different types of IOP's envisaged are: 1) surf aerosol measurements only, 2) transmission measurements only, 3) surf aerosol and transmission measurements, and 4) surf aerosol, and transmission measurements combined with EO systems (IRST/FLIR) performance measurements (i.e. a full EOPACE IOP).

3.2 The Experimental Sites

The time-line (Table I) shows the IOP's that have or will take place in the area around Monterey or San Diego in Southern California, Duck in North Carolina, Wallops Island in Virginia, and on the west coast of Australia. The following sections describe the sites in Southern California, and the types of measurements that have been performed at each site. The other sites are not discussed, as they have not yet hosted any trials.

TABLE I
EOPACE Time-line

DATE (dd/mm/yy)	PURPOSE
03/10/1995 - 05/10/1995	Scientific Committee meeting, (San Diego, California)
14/11/1995 - 16/11/1995	Participants meeting (San Diego, California) - IRST/FLIR meeting (Nov. 14) - Transmission meeting (Nov. 15) - Surf & Air Mass Characterization meeting (Nov. 16)
22/01/1996 - 09/02/1996	Surf Aerosol IOP #1 (San Diego, California)
04/03/1996 - 15/03/1996	Surf Aerosol/Transmission IOP #2 (Monterey, California)
25/03/1996 - 13/04/1996	EOPACE IOP #3 (San Diego, California)
12/08/1996 - 14/08/1996	Workshop and Scientific Committee meeting (San Diego, California)
04/11/1996 - 22/11/1996	EOPACE IOP #4 (San Diego, California)
31/03/1997 - 11/04/1997	Surf Aerosol IOP #5 (San Diego, California)
30/07/1997 - 31/07/1997	Workshop (San Diego, California)
25/08/1997 - 05/09/1997	EOPACE IOP #6 (San Diego)
08/12/1997 - 10/12/1997	Scientific Committee meeting (San Diego)
xx/02/1998 - xx/02/1998	Surf Aerosol IOP #7 (Duck, North Carolina))
xx/05/1998 - xx/06/1998	Transmission IOP #8 (7 km; San Diego, California)
xx/03/1999 - xx/04/1999	? Surf Aerosol IOP (Duck, North Carolina)
xx/05/1999 - xx/06/1999	? EOPACE IOP (Wallops Island, Virginia)
xx/xx/2000 - xx/xx/2000	? EOPACE IOP - desert dust (west coast of Australia)

3.2.1 Monterey, California

Figure 1 depicts the location of the experimental sites (●'s) in the Monterey area and the location of four buoys (△'s) for which data is available. The pier at Moss Landing was used for making measurements of surf aerosol production, and was the preferred location for visible and IR sources used during the transmission and refraction measurements. The receiver end for these measurements was located in downtown Monterey at the other end of the 23 km transmission path. Meteorology close to the path was obtained using the Naval Postgraduate School's (NPS in Monterey) Mean Buoy positioned near the midpoint of the transmission path, from a TNO meteorological station on the pier at Moss Landing, and from SPAWAR's meteorology (met) box. The met box is a portable met station which was either

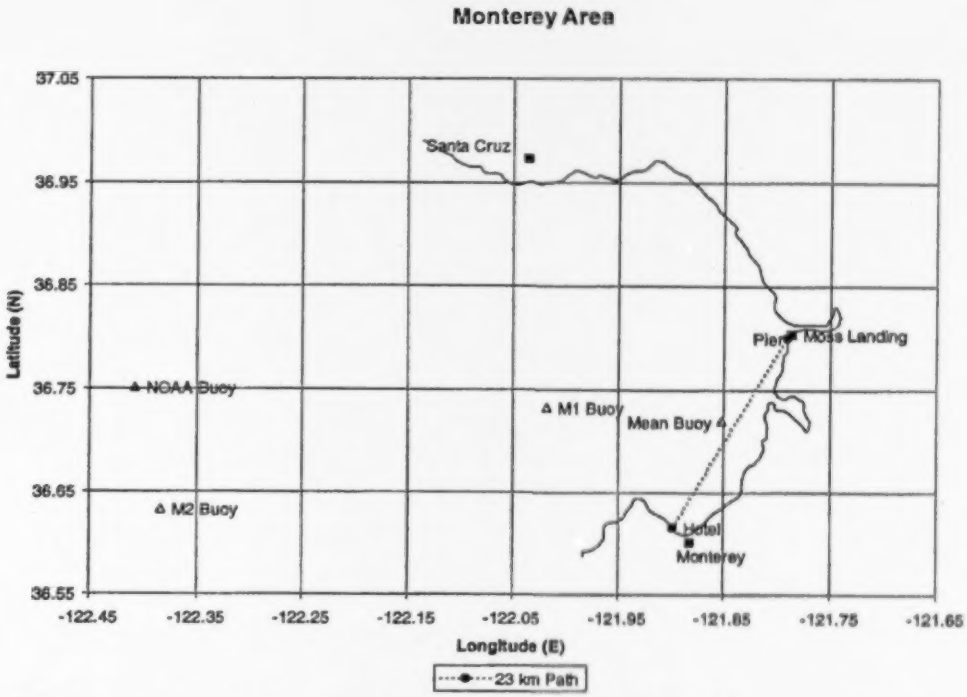

FIGURE 1 - Map of Monterey Bay showing the locations of the two ends of the transmission path and the locations of the four buoys

placed on the wharf or suspended at varying elevations above the sea. Table II shows the characteristics and measured meteorological parameters of NPS's two buoys, Table III that of the met station, and Table IV that of the met box. Table V shows the characteristics of the M1 and M2 buoys which belong to the Monterey Bay Aquarium Research Institute (MBARI), and which were about 15 km west and 50 km west-south-west of the Mean buoy, respectively. The characteristics of the NOAA (National Oceans and Atmospheric Agency) buoy, about 50 km east of the Mean buoy, are given in Table VI.

TABLE II

Characteristics of NPS's Mean and Flux Buoys

Measurements are normally 10 min. averages

Measurement	Sensor	Height above WL (m)	Units
Wind Speed	Young wind monitor	4.88	m/s
Wind Direction	Young wind monitor (from true North)	4.88	deg.
Air Temperature	Rotronics RH/T sensor	4.09	°C
Relative Humidity	Rotronics RH/T sensor	4.09	%
Air Pressure	Barometer	0.38	mb
Sea Temperature	Everest IR probe	-	°C
Turbulence*	Gill solent sonic anemometer	5.09	-
Wave Characteristics*	Accelerometer	-	m
* - only measured by the Flux buoy.			

TABLE III

Parameters measured by the Meteorological Station

Measurement	Sensor	Height above MWL (m)	Units
Wind Speed	-	10.0	m/s
Wind Direction	-	10.0	deg.
Air Temperature	-	4.0	°C
Relative Humidity	-	4.0	%
Atmospheric Pressure	-	6.0 ?	hPa
Sea Temperature	-	0.5 from bottom	°C

TABLE IV

Parameters measured by the Meteorological Box

Measurement	Sensor	Height above MWL* (m)	Units
Electric Field Mill	-	4.0	V
CN Counter	Condensation nuclei	4.0	-
Visible Extinction	PVM	4.0	-
Aerosol Size	Aerosol spectrometer and rotorods	4.0	-
Air Temperature	-	4.0	°C
Relative Humidity	-	4	%
Wave Height	Sonic sensor	-	m
Sea Temperature	Infrared sensor	-	°C
* - assumes the box is on the pier; this was not always the case			

TABLE V
Characteristics of the MBARI's M1 and M2 Buoys
All measurements are hourly averages

Measurement	Sensor	Height above WL (m)	Units
Wind Speed	-	3.6	m/s
Wind Direction	-	3.6	deg.
Air Temperature	-	2.0	°C
Relative Humidity	-	2.0	%
Sea Temperature	-	-	°C

TABLE VI
Characteristics of NOAA's Buoy
All measurements are hourly averages

Measurement	Sensor	Height (m)	Units
Wind Speed	Vane directed impeller	5.0	m/s
Wind Gust	Vane directed impeller	5.0	m/s
Wind Direction	Vane & digital magnetic compass	5.0	deg.
Air Temperature	Thermistor	4.0	°C
Sea Temperature	Thermistor	-0.5	°C
Air Pressure	Variable capacitance	0.0	mb
Wave Height	Accelerometer	0.0	m
Dominant Wave Period	Accelerometer	0.0	sec.
Average Wave Period	Accelerometer	0.0	sec.
Mean Wave Direction	Heave, pitch & roll magnetometer	0.0	deg.

3.2.2 Southern California and San Diego

To date, various sites have been used by the many groups that have participated in the different Southern California IOP's. Figure 2 shows the larger area between Santa Barbara and San Diego where measurements have been obtained, while Fig. 3 shows, in more detail, the sites located in the immediate San Diego area. Measurements obtained from Pt. Mugu, Long Beach, San Diego, San Nicolas Island and San Clemente Island (see Fig. 2) are principally concerned with measurements involving the characterization of the air mass over the region. On the other hand, the sites in the San Diego area (see Fig. 3) have been used to study the production of surf aerosols (pier at Scripps Institute, Imperial Beach pier,

and Coronado Beach), transmission and refraction measurements (Subbase, Imperial Beach pier and Coronado), and IRST and polarization studies (Pt. Loma). To complement the measurements over San Diego Bay, NPS's two buoys been installed near the midpoints of the 7 km path (between the Subbase and Coronado) and the 15 km path (between the Subbase and the Imperial Beach pier). The characteristics of the two available buoys are given in Table II.

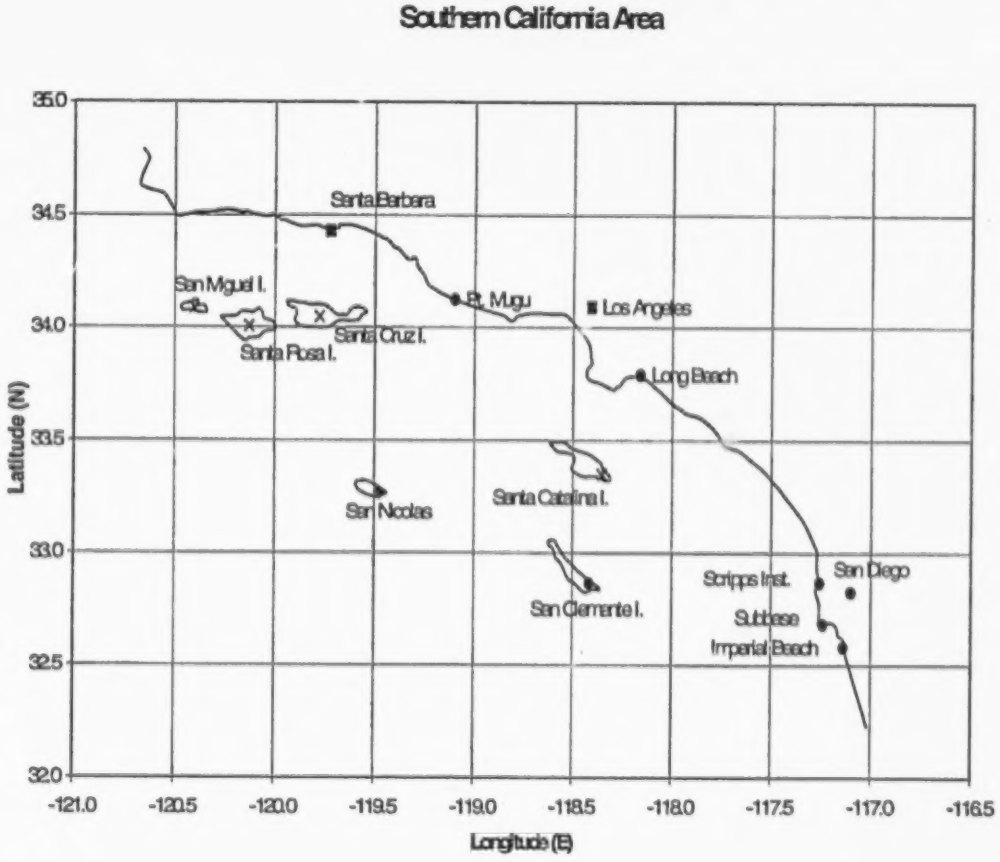

FIGURE 2 - Map of Southern California showing the locations at which different measurements have been taken

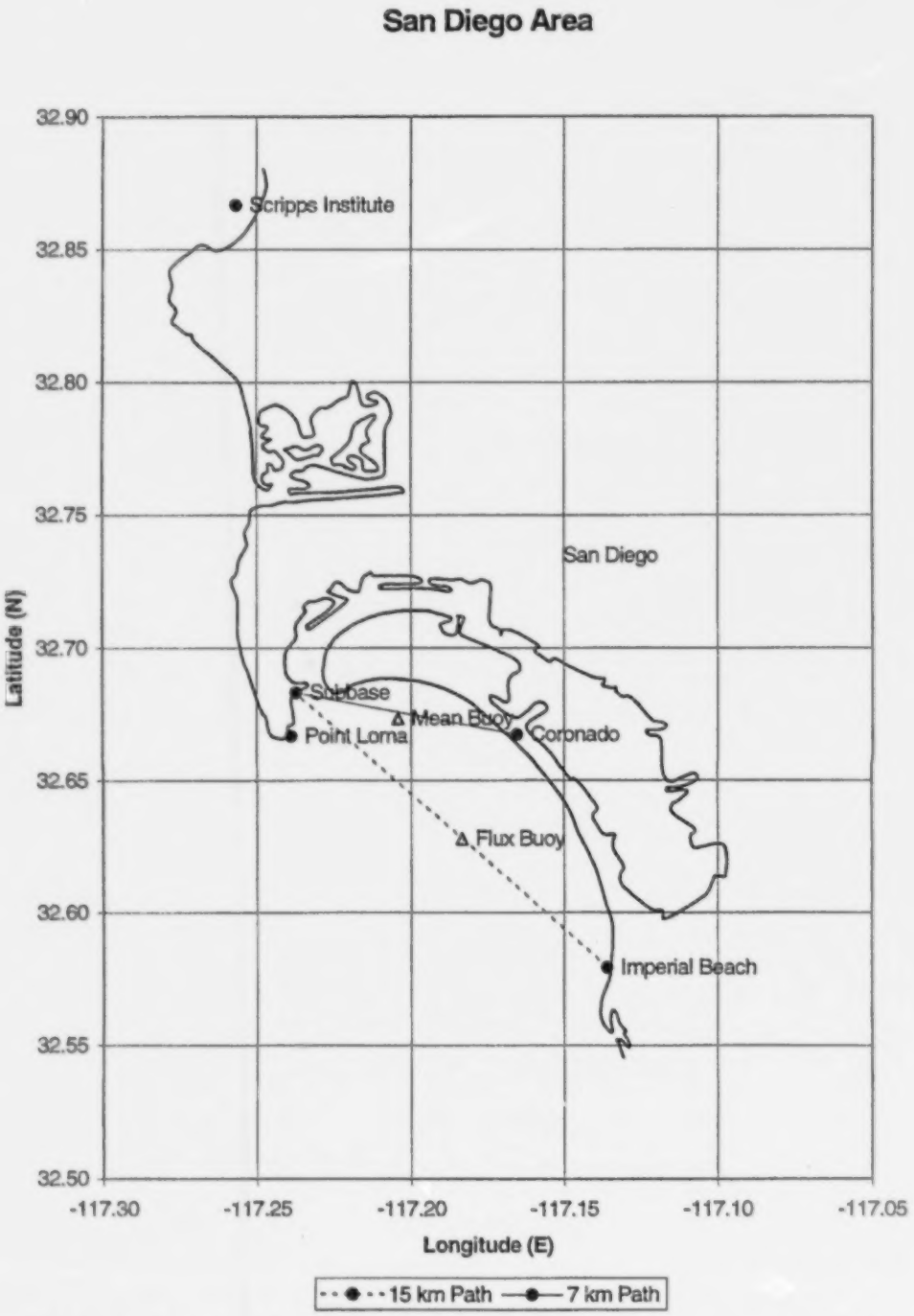

FIGURE 3 - Map of San Diego Bay showing the endpoints of both the 7 and 15 km transmission paths and the locations of the two buoys

3.3 Participants and their Equipment

Appendix A gives a list of the principal participants and their institution. Table VII shows the names of the various institutions that have participated in EOPACE, their acronyms, and their points of contact. Tables VIII - XII show the types of instrumentation they can provide, where it was used, and the general purpose of their measurements. Table VIII shows these for the surf aerosol measurements, Table IX for the Air Mass Characterization measurements, Table X and XI for the Near Ocean Transmission and Refraction measurements at San Diego and Monterey, respectively, and Table XII for the EO System Performance measurements. None of these Tables should be considered to be either complete or final, as instruments may be placed somewhere else, added to the set of measurements, or removed from the set of measurements. Nevertheless, they do give an idea of the trial's significant assets.

TABLE VII
The Institutions

Institution	Acronym	Point of Contact
Defence Research Establishment Valcartier	DREV	Luc Forand
Office of Naval Research	ONR	Ron Ferek
Naval Air Warfare Center	NAWC (Pt. Mugu)	Jay Rosenthal
Naval Postgraduate School	NPS	Ken Davidson
Space and Naval Warfare Systems Center	SPAWAR	Douglas Jensen
Naval Research Laboratory	NRL	Andy Goroch
Pennsylvania State University	PSU	Russ Philbrick
University of Western Australia	UWA	Brett Nener
Physics and Electronics Laboratory TNO	TNO	Gerrit de Leeuw
University of Sunderland	US	Mike Smith
Scripps Institute of Oceanography	SIO	

TABLE VIII
Surf Production

Purpose	Instrumentation	Participating Institutes
Generation & Surf Characterization	Surf Bubbles(Acoustic & Optical)	TNO, NRL
	Wave Characterization (Height & Period)	SIO
	Surf Video	SIO, SPAWAR, US

Surf Production (fresh aerosols)	Electric field & space charge density	SPAWAR, NAWC
Surf Profiling	Aerosol Package[1] - Aerosols - Rotorods - Meteorology - Visibility (HSS) - IR Extinction (PVM)	SPAWAR
Surf Plume Structure	Lidar (LARS)[2] Fixed Target Bistatic Camera Tristatic Imaging	PSU PSU PSU
Surf Aerosol/Extinction	IR Transmission (Broad Band & Spectral) IR & Visual Extinction	SPAWAR NAWC
Non-surf aerosol characterization	Aerosol Concentrations Aerosol Composition CN, Rn, Soot Carbon Nephelometer	US, TNO, SPAWAR, NPS US SPAWAR, US, NAWC TNO
Meteorology	Standard parameters Turbulence (Sonic Anemometer)	SIO, NAWC, SPAWAR TNO, US

1 - portable aerosol package for measuring horizontal and vertical profiles.
2 - safety problems limit lidar application.

TABLE IX

Air Mass Characterization[1]

Location	Instrumentation	Participating Institutes[2]
San Diego	Sun photometer (SP) CN, Rn, Radiosondes (RS)	SPAWAR, PSU SPAWAR
Long Beach	SP, CN	SPAWAR
San Nicholas Island	SP, CN, RS	NAWC
San Clemente Island	SP, CN, RS	SPAWAR
Point Mugu	SP, CN, RS	NAWC
Satellite Platform	AVHRR	NPS
SPAWAR Airborne Platform	Aerosols & Meteorology	SPAWAR
NPS Point Sur	Soot Carbon, Aerosol Chemistry Rn SP, CN, RS, Aerosols, Meteorology Lidar (Vertical Structure)	US SPAWAR, NAWC NPS TNO

1 - Purpose: Determine if the air mass parameters in various coastal locations can be determined from satellite imagery and to provide a data base for initializing and testing the mesoscale coastal aerosol models being developed.
2 - air mass characterization is supported meteorologically by the California Air Resource Board.

TABLE X

Near Ocean Surface Transmission - San Diego[1]

Location/Purpose	Transmission Instrumentation	Participating Institutes
Source end of path - meteorology and sources	7 km Transmissometer Source (Naval Amphibious Base) - Broadband IR source - Meteorological Equipment - Visible sources 15 km Transmissometer Source (Imperial Beach Pier)[2]	 SPAWAR SPAWAR, US, NAWC DREV

	- Visible & IR sources - Meteorological Equipment	TNO, DREV TNO, DREV
Receiver end of path - meteorology & receivers	7 & 15 km Transmissometer Receivers (Navy Submarine Base)[2] - Broadband IR receivers - Meteorological Equipment - Video recording of visible sources	 SPAWAR, TNO TNO, SPAWAR, DREV DREV
Mid path meteorology	Buoys on both 7 & 15 km Transmission Paths[2] - Meteorology - Cn^2 Turbulence - Wave Characterization Boat Sailing along the 7 & 15 km Paths[2] - Surf Aerosol Package[3] - Other meteorology - Visible & IR sources	 NPS NPS NPS SPAWAR DREV DREV, TNO
Near path meteorology	North Island Naval Air Station - Meteorology	 SPAWAR

1 - Purpose: Quantify IR propagation characteristics for near ocean surface transmission.
2 - IOPs only.
3 - Instrumentation package is the same as that used for the surf production effort.

TABLE XI

Low Level Near Surface Transmission - Monterey[1]

Location/Purpose	Transmission Instrumentation	Participating Institutes
Source end of 23 km path - meteorology, etc.	Transmissometer Source (Moss Landing)[2] - Broadband IR Source - Visible sources - Aerosols - Nephelometer (TSI) - Meteorological Station - Sonic anemometer Lidar (LARS)**	 TNO DREV TNO NRL TNO TNO PSU
Receiver end of 23 km path	Transmissometer Receiver (Monterey)[2] - Broadband IR Detector - Visible cameras	TNO NPS DREV
Mid path meteorology	Buoy mid path on Transmission Path[2] - Wave Characterization - Meteorology	NPS

1 - Purpose: Quantify IR propagation characteristics for near ocean surface transmission.
2 - IOP's only.
3 - Lidar safety may limit operations.

TABLE XII

EO Systems Performance - EOPACE[1]

Location/Purpose	Instrumentation	Participating Institutes
Pt. Loma (SPAWAR) - near Cabrillo Lighthouse - IRST Performance - Polarization Effects	IRST Dual-band (mid & far IR) Polarization Imager Polarimeter (3-5 :m)	SPAWAR NPS NSWC
Pt. Sur - calibrated IR sources - meteorology - IRST, FLIR performance - polarization effects	Calibrated IR targets Meteorology Ship Temperature Sensors	SPAWAR NPS NPS
Navy Combatants and other targets of Opportunity - IRST, FLIR performance - polarization effects - ship signatures	Cruise conditions, position coordinates, meteorology, etc.	US Navy Combatants
High Speed Surface Boat - IRST detection of low profile/ high speed surface boats	Position coordinates & cruise conditions	SPAWAR
FLIR Instrumented Aircraft (P3/FA18) - FLIR performance	FA18's operational FLIR's AGEMA on P3	US Navy SPAWAR
Transmission Paths - refraction and scintillation on near surface transmission paths	Visible & IR sources Visible & IR Imagers	DREV, TNO DREV, TNO

1 - Purpose: Evaluation of IRST/FLIR and imaging systems operating within a coastal region for differing land/sea/sky backgrounds.

4.0 DREV's PARTICIPATION

Due to DREV's interest in the performance of infrared (IR) systems, such as IRST's (Infrared Search and Track), FLIR's (forward-looking IR), and rangefinders, over horizontal paths less than 20 m above the sea surface, we have become increasingly involved in studying the optical effects of the marine boundary layer (MBL). In 1993, we participated in the Marine Aerosol Properties and Thermal Imager Performance (MAPTIP) trial off the coast of The Netherlands in the North Sea, and we are currently involved in both the US sponsored EOPACE program, and NATO's LAPTEX program. The importance of these joint international trials is to leverage the resources of many research groups so that all may benefit from the measurements of others. In this respect, DREV is able to offer its expertise

and equipment for the measurement of atmospheric refraction, turbulence, visibility, IR extinction, and other meteorological parameters. These data, can then be tested against various computer models which DREV and others have developed over the last number of years.

To date DREV has participated in the March 1996 IOP in Monterey (IOP #2), the April 1996 IOP in San Diego (IOP #3), and the August 1997 IOP in San Diego (IOP #6). It has also sent equipment for the month long transmission measurements planned for May of 1998 (IOP #8). DREV has also been involved in the analysis of the transmission data from the November 1996 IOP in San Diego (IOP #4). DREV's contributions to these IOP's are presented in the following sections.

4.1 March 1996 - Monterey (IOP #2)

For the March 1996 IOP in Monterey, California, DREV set up a series of 500 W halogen lamps on the pier at Moss Landing (see Fig. 1). Figure 4 shows a schematic of the actual setup. It doesn't give the actual measured heights of the lamps above the mean water level (MWL), but they are quite representative. Several IR sources were also installed; however, their performance was less than satisfactory during the trial.

At the other end of the 23 km transmission path, two visible cameras and an AGEMA (far IR) camera were installed in the Plaza Hotel located in downtown Monterey (see Fig. 1),

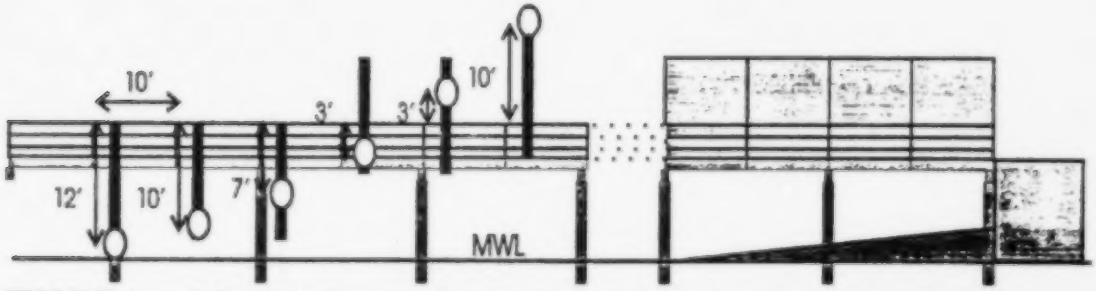

FIGURE 4 - Schematic diagram showing the approximate arrangement of DREV's 500 W halogen lamps at Moss Landing pier

and trained on our light sources. A visible CCD camera, with a 2-meter focal length telescope, and the AGEMA camera were installed on the third floor approximately 13 m above the mean water level (MWL). The second visible CCD camera, with a 1.3 meter focal length telescope, was installed on the fourth floor at 16 m above the MWL. The video signals from all three cameras were recorded with time-codes on three SVHS video recorders, and monitored on two video monitors installed on the third floor. No in-depth analysis has yet been done on this data; however, along with TNO's transmission measurements, it is definitely worth a good look. Graphs showing the general meteorological conditions during this campaign are given in Figs. 5 to 8. As can be seen, the water temperature was generally between 14 and 16 °C with a diurnal variation of 1 to 2 degrees. The air temperature varied in large part from about 10 °C to 16 °C each day, except from March 6th to March 8th where a low of 6 °C was reached on March 6th and maximum temperatures above 20 °C were reached on each of the three days. Thus, significant occurrences of both negative and positive air-sea temperature differences (ASTDs) were measured. The effects of these temperature swings can also be seen in the relative humidity graph, where it drops from its normal value between 70 and 100% to below 40%. With the wind, we note that in general the winds are from an easterly (land) direction in the morning and continuously increases until about 10 a.m. Subsequently, it decreases to a minimum near noon, changes to come from the west (pacific ocean), and increases to a maximum near 3 p.m. It then falls to a minimum the following morning and the cycle repeats.

4.2 April 1996 - San Diego (IOP #3)

For the April 1996 IOP in San Diego, California, DREV set up a series of 500 W halogen lamps on the pier at Imperial Beach (see Fig. 9). The figure only shows a schematic representation of the actual setup and does not give the actual measured heights of the lamps above the mean water level (MWL).

At the other end of the 15 km transmission path, two visible cameras and an AGEMA

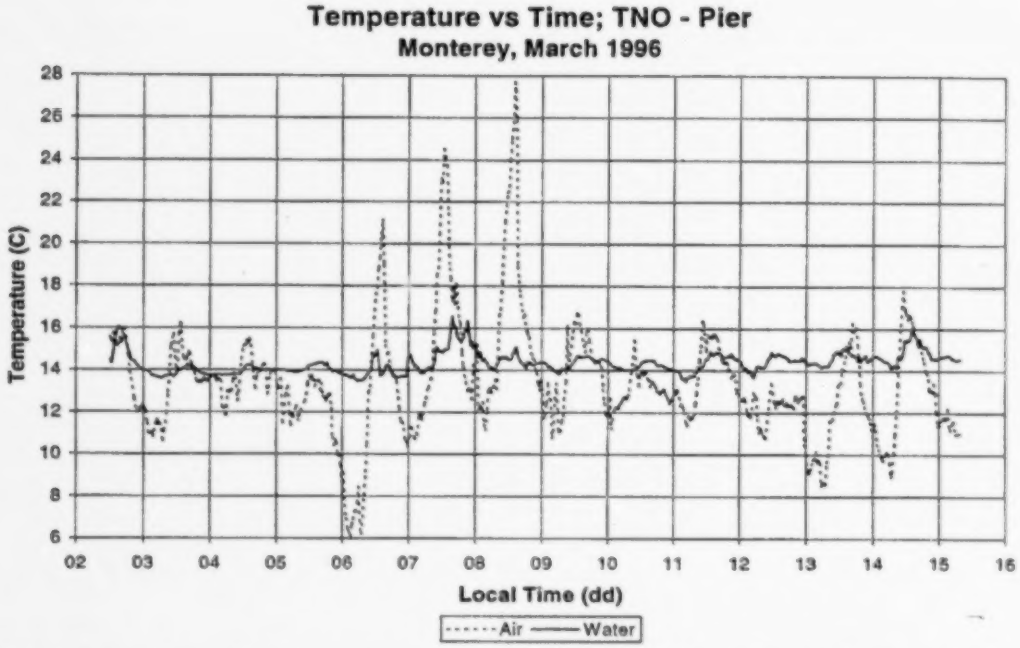

FIGURE 5 - Air and water temperature measured by TNO at the Moss Landing pier

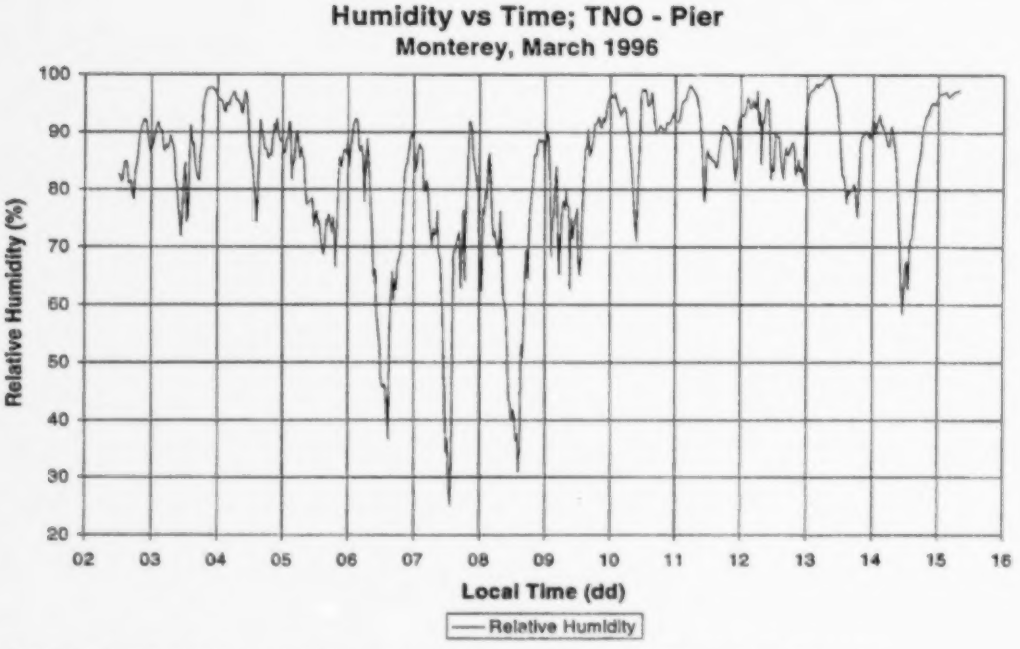

FIGURE 6 - Relative humidity measured by TNO at the Moss Landing pier

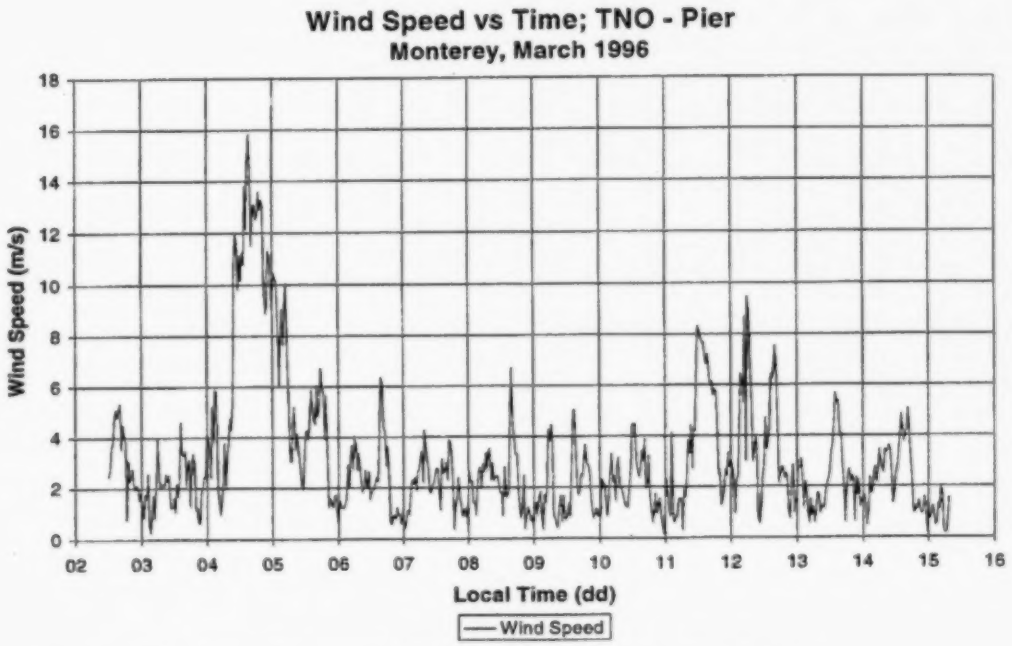

FIGURE 7 - Wind speed measured by TNO at the Moss Landing pier

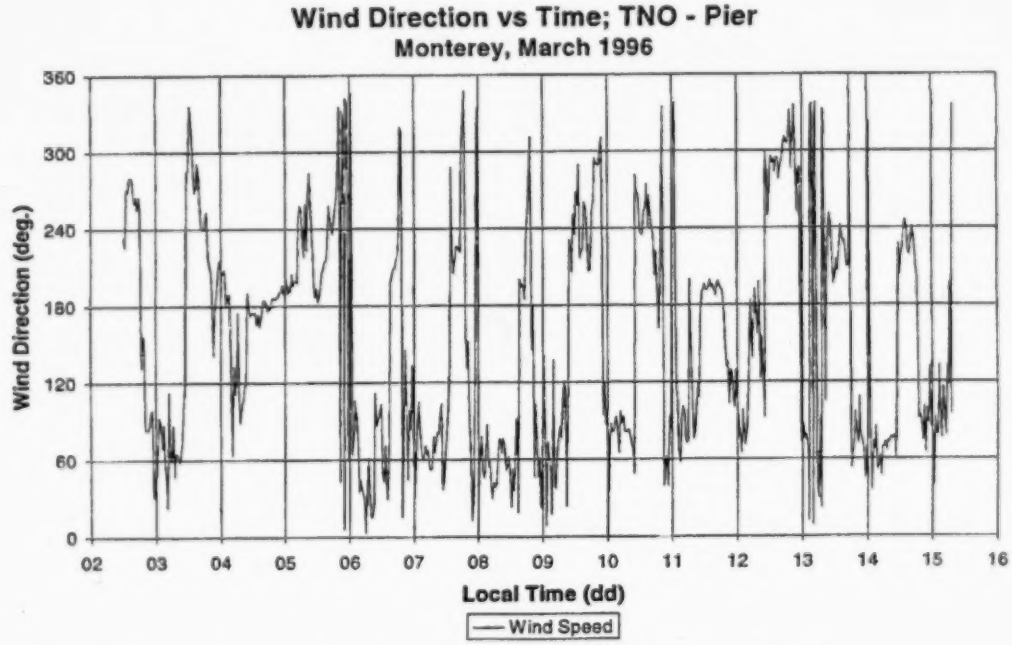

FIGURE 8 - Wind direction measured by TNO at the Moss Landing pier

(far IR) camera were installed near a trailer installed at the Subbase (see Fig. 3). A visible CCD camera with a 2 meter focal length telescope, and the AGEMA camera were installed near the trailer about 4 meters above the MWL. A second visible CCD camera, with a 1.3 meter focal length telescope, was situated about 8 meters above the MWL. The video signals from all three cameras were recorded, with time-codes, on two SVHS video recorders, and monitored on two video monitors installed inside the trailer. An HSS visibility meter was also mounted on a pole outside the trailer about 6.6 meters above the MWL.

A small 16 foot boat (a Boston Whaler) was used during this IOP to take measurements of various meteorological parameters and to make aerosol measurements along both the 7 and 15 kilometer transmission paths. To improve our ability to track the boat and to get an idea as to the maximum inter-vision range (MIVR) between our cameras and the boat, we installed a small IR source and a 500 W halogen lamp about 2.2 meters above the boats

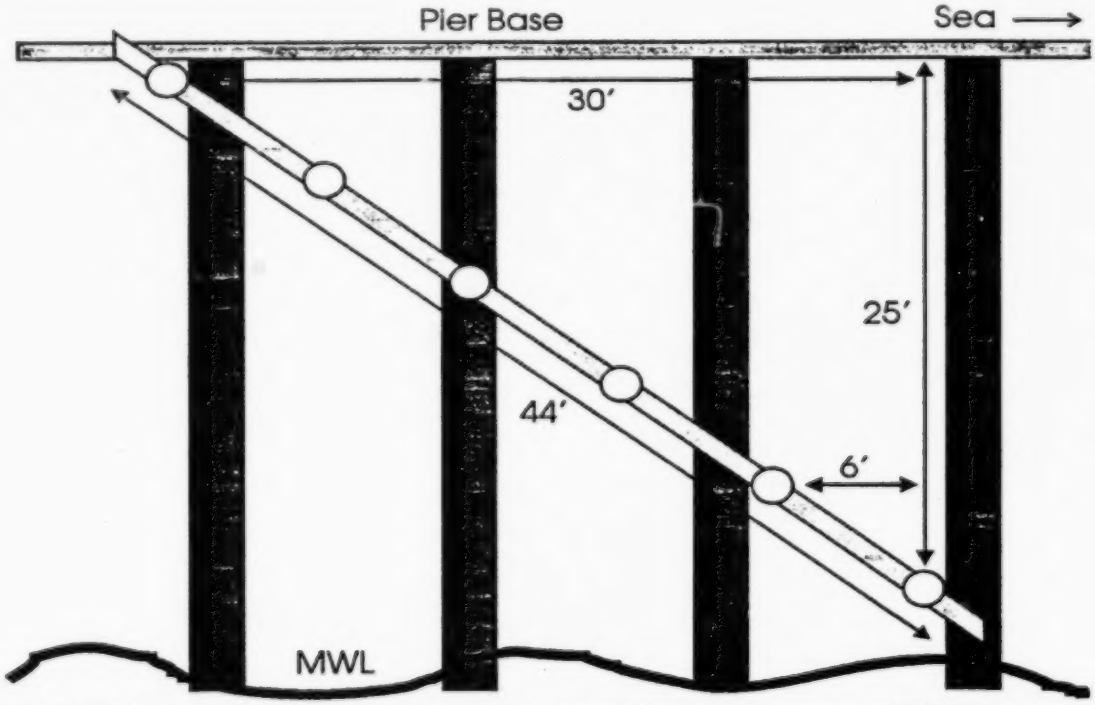

FIGURE 9 - Schematic diagram showing the approximate arrangement of DREV's 500 W halogen lamps at the Imperial Beach pier

water level (WL).

Some of the data for this trial has been studied in some detail (Ref. 10, 11). Nevertheless, it does need to be looked at again and incorporated into the analysis required on the data from subsequent IOP's. Graphs showing the general meteorological conditions during this campaign, as measured by the Mean Buoy, are given in Figs. 10 to 13. As can be seen, the water temperature hovered around 16 °C with a diurnal variation of less than 2 degrees. Differences from this pattern occurred from April 5th to April 7th and on April 14th, when it varied by as much as 4 degrees and reached maximums near 18 °C. In contrast, the water temperature fell by about 2 degrees from March 8th to 11th. Meanwhile, the air temperature varied in large part from about 10 °C to 16 °C each day, except during the Santa Anna winds from April 6th to April 8th where a low of 16 °C was reached on March 6th and maximum temperatures above 20 °C were reached on each of the three days. The effects of these winds can also be seen in the relative humidity graph, where it drops from its normal value between 70 and 100% to below 40%. With the wind, we note that in general the winds are from an easterly (land) direction in the morning and continuously increases until about 10 a.m. Subsequently, they decrease to a minimum near noon, change to come from the west (pacific ocean), and increase to a maximum near 3 p.m. Then, they fall to a minimum the following morning before the cycle repeats.

4.3 November 1996 - San Diego (IOP #4)

For the November 1996 IOP in San Diego, California, much the same setup as for IOP #3 was used by the participants. DREV did not actively participate in this trial; nevertheless, we have modelled some of the measured transmission data (Ref. 12) by making use of the measured meteorological data. Graphs showing the general meteorological conditions during this campaign, as measured by the Flux Buoy, are given in Figs. 14 to 16. As can be seen, the water temperature hovered around 16 °C with a diurnal variation of less than 2 degrees. Differences from this pattern occurred from Nov. 14th to Nov. 17th and from

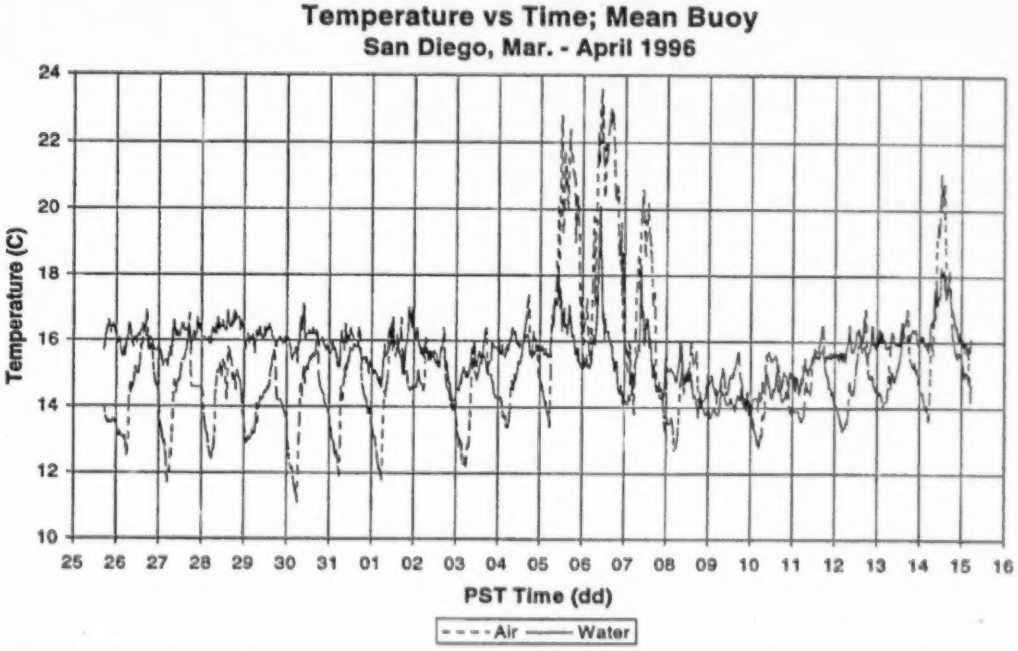

FIGURE 10 - Air and water temperature measured by the Mean Buoy at San Diego

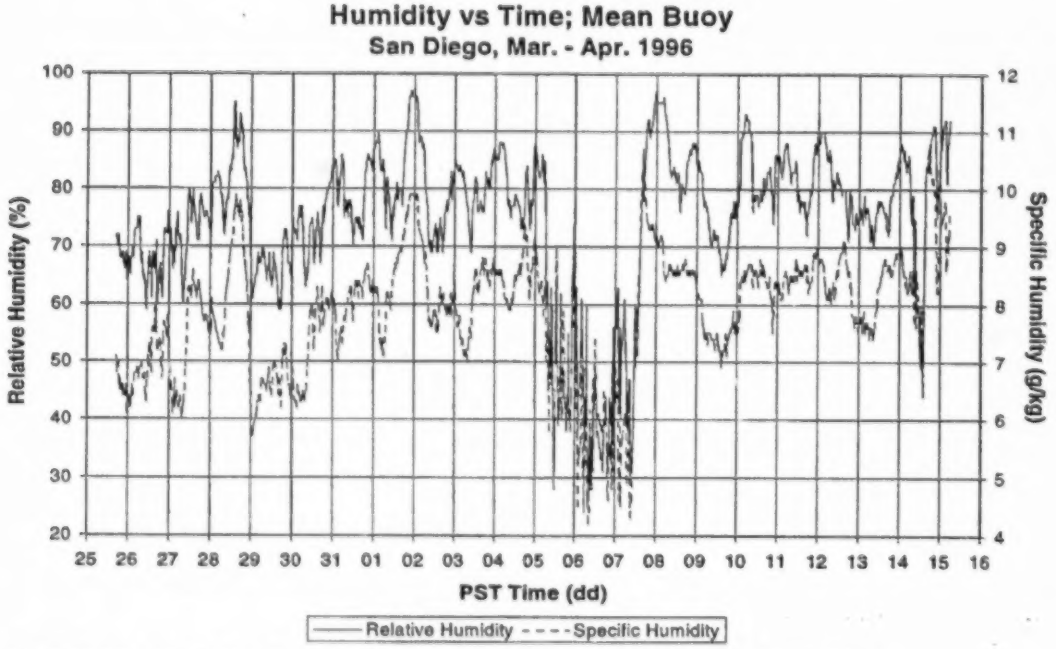

FIGURE 11 - Relative humidity measured by the Mean Buoy at San Diego

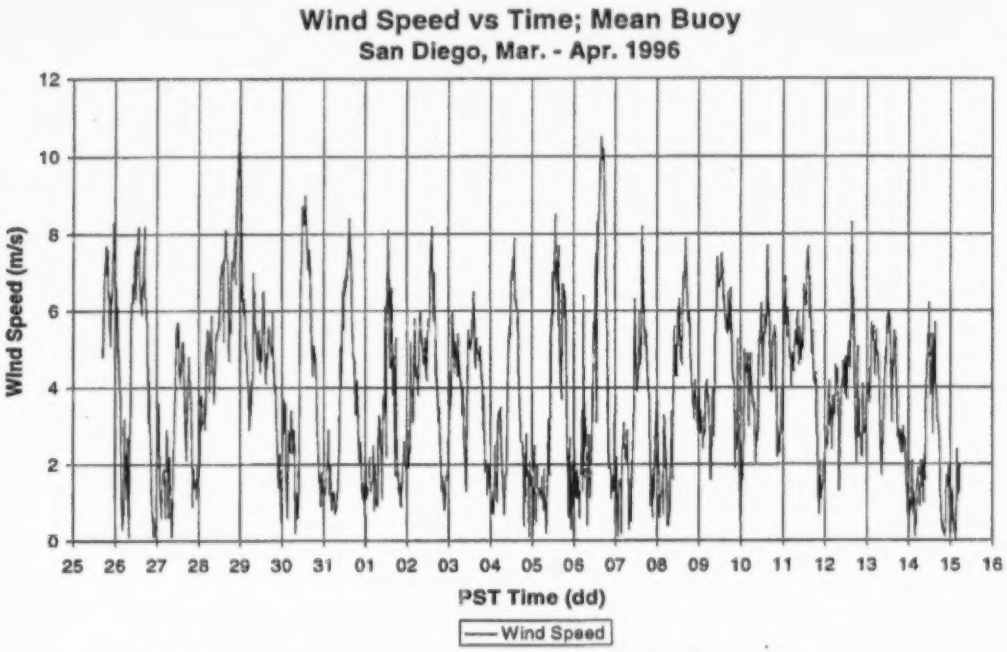

FIGURE 12 - Wind speed measured by the Mean Buoy at San Diego

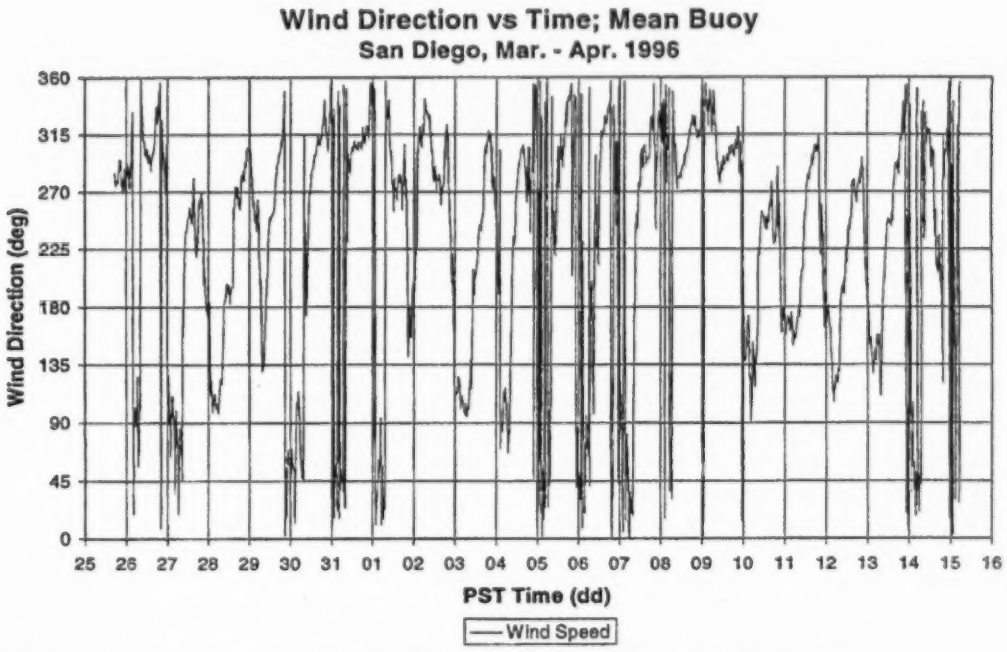

FIGURE 13 - Wind direction measured by the Mean Buoy at San Diego

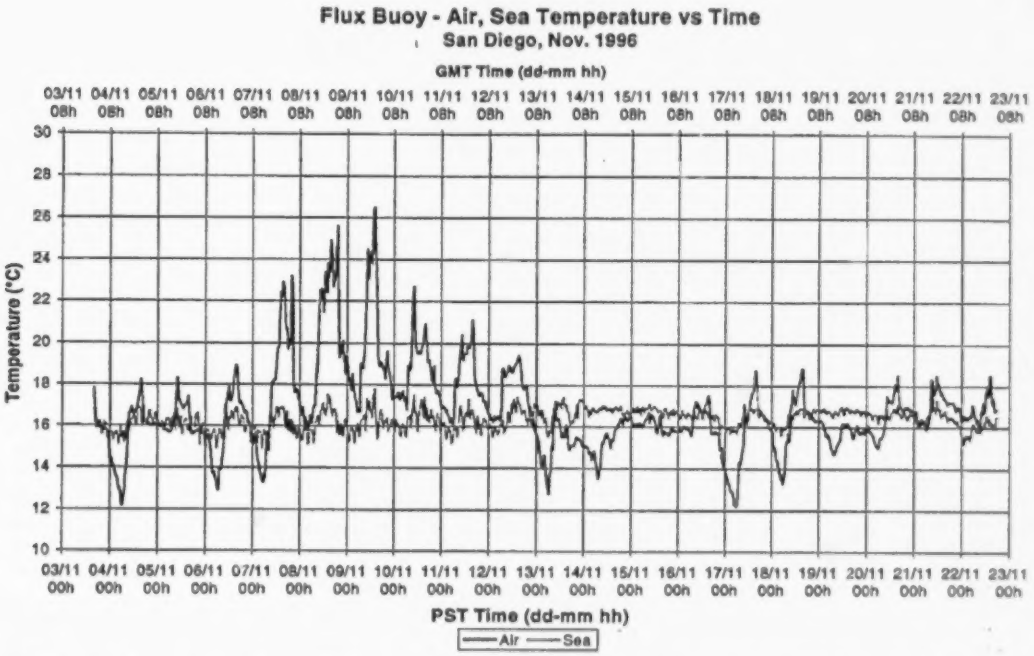

FIGURE 14 - Air and water temperature measured by the Flux Buoy at San Diego

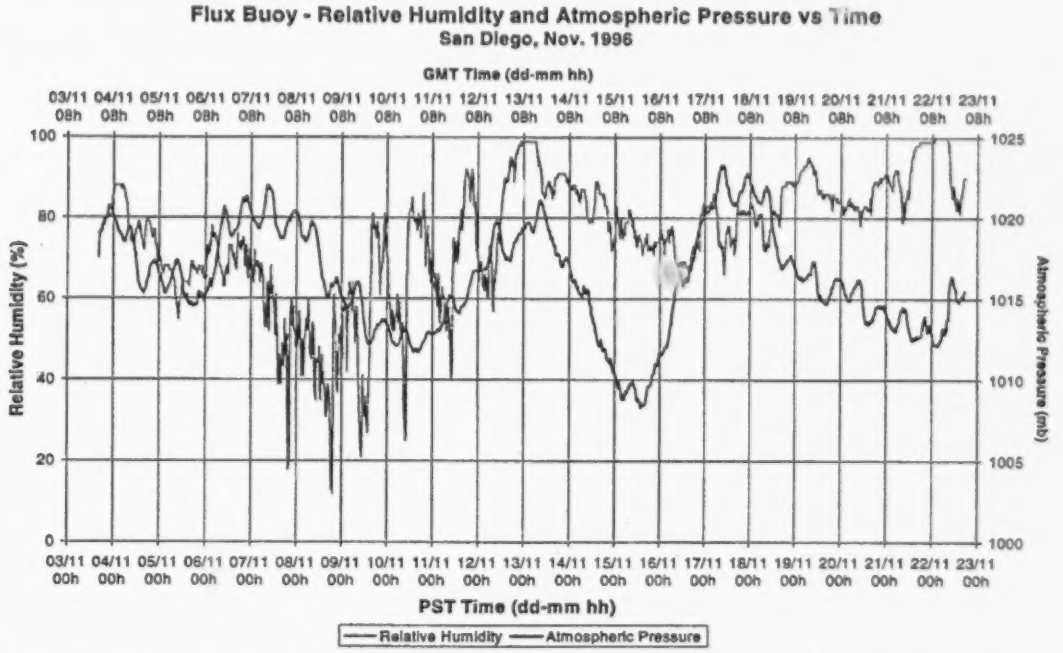

FIGURE 15 - Relative humidity and atmospheric pressure measured by the Flux Buoy at San Diego

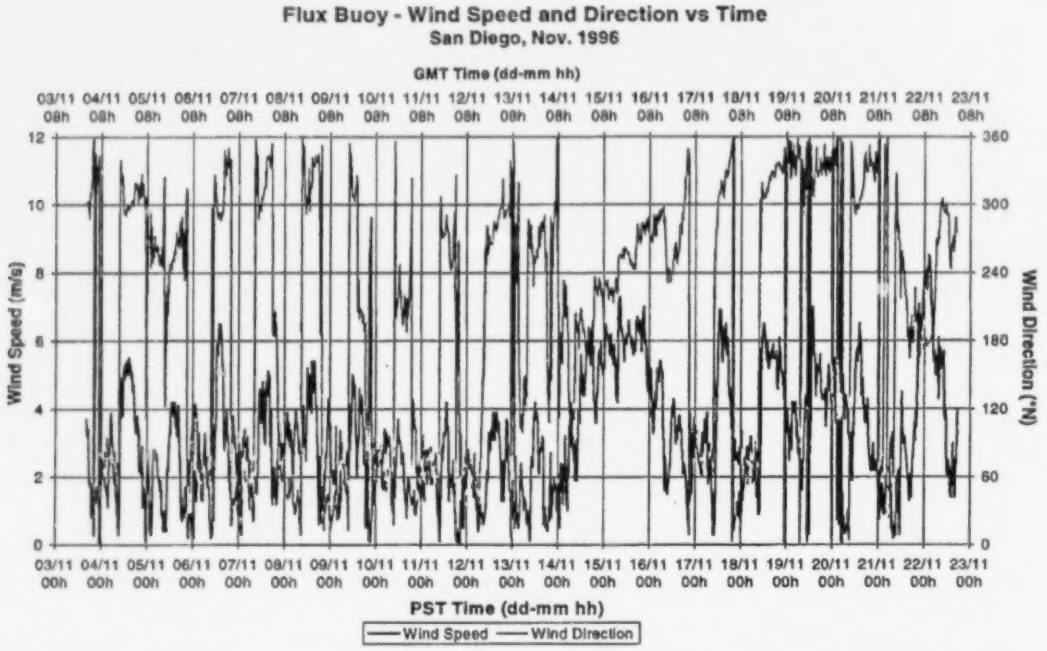

FIGURE 16 - Wind speed and direction measured by the Flux Buoy at San Diego

Nov. 19th to Nov. 21st, when it remained constant at about 17 °C. Meanwhile, the air temperature varied greatly during the trial from a low of 12 °C to a high of 26 °C, with daily variations of 2 to 10 degrees. The effects of these temperature changes can also be seen in the relative humidity graph, where it varies from 20 to 100%. With the wind, we note that in general the winds blow at about 2 m/s from an easterly (land) direction in the morning, change to come from the north, northwest (along the coast) at 4 m/s in the afternoon before quieting down and coming from the land later on in the evening. The most remarkable difference from this behaviour occurred from Nov. 14th to Nov. 17th when the wind blew continuously between 3 and 7 m/s from south, south-west and the water temperature was greater than the air temperature.

4.4 August 1997 - San Diego (IOP #6)

For the August 1997 IOP in San Diego, California, we had much the same setup as

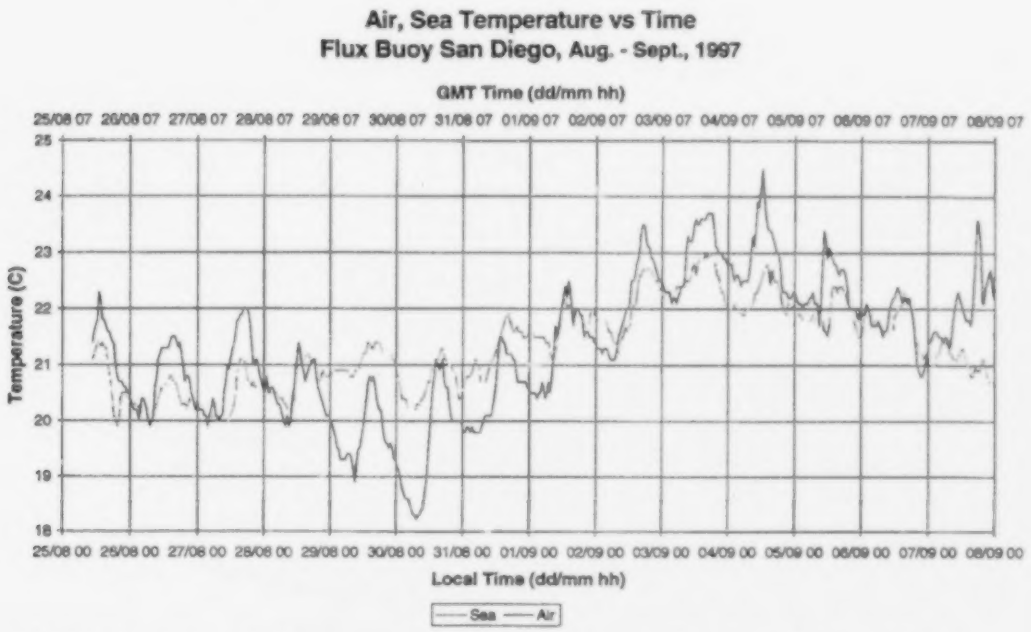

FIGURE 17 - Air and sea temperature measured by the Flux Buoy at San Diego

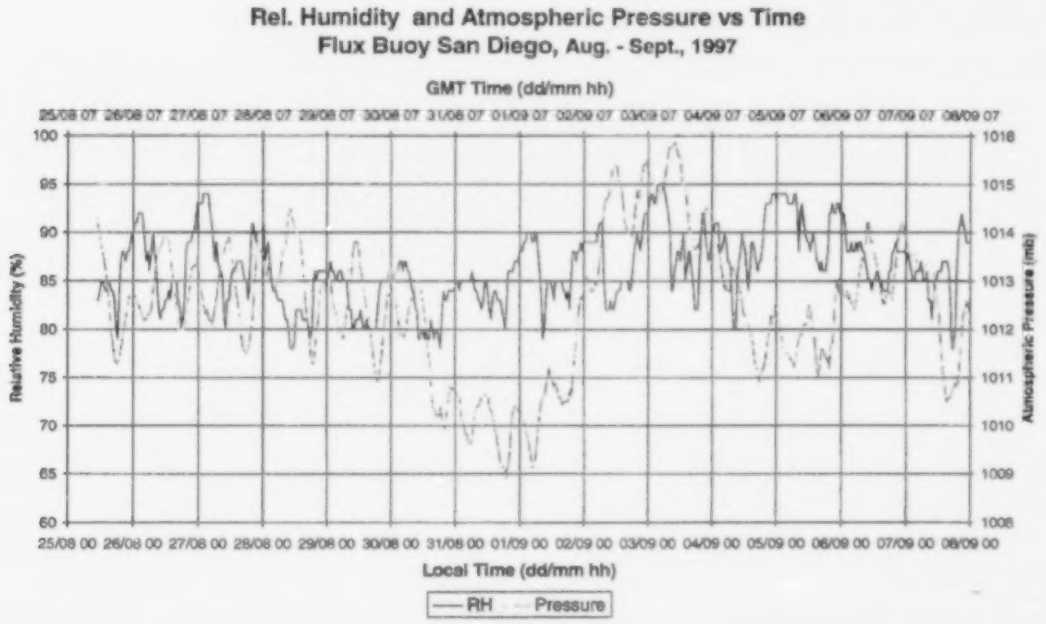

FIGURE 18 - Relative humidity and atmospheric pressure measured by the Flux Buoy at San Diego

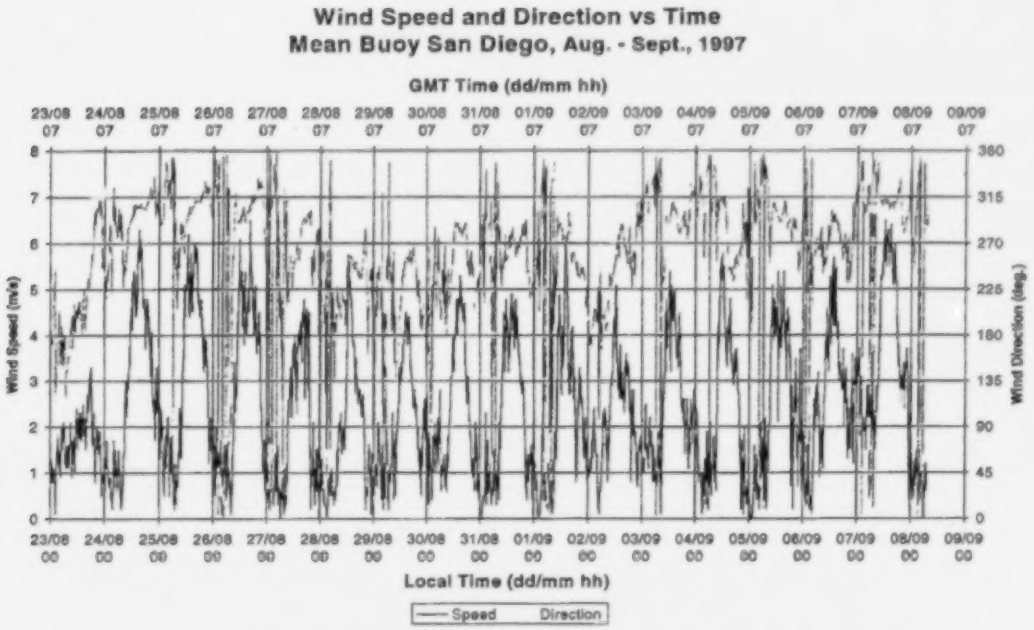

FIGURE 19 - Wind speed and direction measured by the Mean Buoy at San Diego

for IOP #3 in San Diego. We installed 500 W lamps at the Imperial Beach pier as in Fig. 9, and three lamps to the structure supporting the IR source at Coronado Beach (see Fig. 3). An HSS visibility meter was installed at the Subbase, and a second HSS along with an IR extinction meter (Gerber) and a sun photometer were installed on the pier at Imperial Beach. The two visible cameras with their respective telescopes were trained exclusively on the light sources either at Imperial Beach or at Coronado Beach. Graphs showing the general meteorological conditions during this campaign, as measured by the buoys, are given in Figs. 17 to 19. As can be seen from the Flux Buoy, the water temperature varied between 20 and 23 °C with a diurnal variation of less than 1 degree. The air temperature varied from 18 to 24 °C, with daily variations of 1.5 to 3 degrees. The effects of these temperature changes can also be seen in the relative humidity graph, which varies from 80 to 95% with diurnal variations of 10 to 15 percent, and even in the atmospheric pressure. As for earlier trials, we note that in general the winds are light (below 2 m/s) in the morning, change to come from the north, northwest (along the coast) between 4 and 6 m/s in the afternoon before quieting

down later on in the evening. No significant departures from this pattern are observed in the weather data and DREV has not performed any analysis on this data set apart from some visibility and aerosol extinction calculations.

5.0 CONCLUSIONS

To date, the EOPACE trial has been quite successful in achieving some of its goals, notably with respect to measurements of the meteorology, measurements of the aerosols, transmission measurements, and the comparison of these measurements with model calculations. This last topic is of particular interest to DREV and is the subject of much of our efforts (Ref. 10, 11 & 12). Due to the wealth of the unique sets of data collected during the last couple of years, for which their analysis is still in its infancy, we can expect many interesting studies to be produced for many years to come. In fact this data set, along with the multinational nature of the trial, will undoubtedly be one of the trial's principal legacies.

6.0 ACKNOWLEDGEMENTS

Thanks must be given to our technician, Luc Gauthier, for his efforts during our participation in various EOPACE IOP's. We would also like to thank the people and staff on Propagation Path Road at SPAWAR in San Diego for their hard work, assistance and cooperation in organizing these trials. In particular, we would like to thank Bill Moison for all his efforts in the installation of our lights on the Imperial Beach pier. We would also like to thank Alf Cooper and others at NPS in Monterey for their hard work, assistance and cooperation during the trial in Monterey. Finally, we must also thank the other participants, particularly those from The Netherlands, in helping to make the EOPACE campaign a continuing source of interesting science, and personal pleasure.

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This memorandum describes the basic objectives of the EO Propagation Assesament in Coastal Environments (EOPACE) trial and gives an account of DREV's participation in EOPACE. Particular emphasis is placed on the two trials held during the spring of 1996 and the trial held in August of 1997.

After the introduction, the memorandum provides some background information on EOPACE and its objectives. The following section sets out the experimental time-line, describes the experimental sites, and lists most of the participants, and their con-tributions to EOPACE. The last section gives a more detailed description of DREV's particpa-tion and particular interests.

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aerosols

molecular absorption

optical propagation

optical transmission